

Theory of Internal Antennas for Mobile Devices

Rob Hill
CEO of AntennaMagic LLC
OCT 10, 2014

About Me:

35 Years working with Antennas

50 US Patents Granted

30 International Patents Granted

600 Million Products with my Antennas Inside

Pioneer in Internal Antenna Design

Maxwell's Equations:

$$\nabla \times \mathbf{E} = -\mathbf{j} \omega \mathbf{v} \mathbf{H}$$

$$\nabla \times \mathbf{H} = \sigma \mathbf{E} + \mathbf{j} \omega \epsilon \mathbf{E}$$

$$\nabla \cdot \mathbf{E} = \rho / \epsilon$$

$$\nabla \cdot \mathbf{H} = 0$$

UNITS:

Electric Field E = Volts/meter

Magnetic Field H = Amps/meter

$j\omega$ = time varying = frequency = ac = d/dt

ρ = charge density = coulombs/meter³

μ = permeability = henrys/meter

ϵ = permittivity = farads/meter

σ = conductivity = mhos/meter

Dimensional Analysis:

Let's use dimensional analysis to glean insight into the equations so they don't seem so abstract and intangible.

Let's find a way to put them "on the workbench" so we can look them over, understand them, and exploit them.

Equation 2: $\nabla \times \mathbf{H} = \sigma \mathbf{E}$

The Hidden Resistor

$$\nabla \times \mathbf{H} = \sigma \mathbf{E}$$

$$\frac{\text{A}}{\text{m}^2} = \left(\frac{1}{\Omega \text{m}} \right) \left(\frac{\text{V}}{\text{m}} \right)$$

$$A = \frac{V}{\Omega}$$

$$I = \frac{V}{R} \quad \text{OHM'S LAW}$$

Equation 2: $\nabla \times \mathbf{H} = j\omega\epsilon\mathbf{E}$

The Hidden Capacitor

$$\nabla \times \mathbf{H} = j\omega\epsilon\mathbf{E}$$

$$\frac{A}{m^2} = \frac{d}{dt} \left[\frac{F}{m} \right] \left[\frac{V}{m} \right]$$

$$A = \frac{d}{dt} [F][V]$$

$F = \text{FARADS} = \text{UNIT OF CAPACITOR}$

$A = \text{AMPS} = \text{CURRENT} = I$

$$I = C \frac{dV}{dt}$$

Equation I: $\nabla \times \mathbf{E} = -j\omega\mu\mathbf{H}$

The Hidden Inductor

$$\nabla \times \mathbf{E} = -j\omega\mu\mathbf{H}$$

$$\frac{\text{V}}{\text{m}} = -\frac{d}{dt} \left[\frac{\text{HENRY}}{\text{m}} \right] \left[\frac{\text{A}}{\text{m}} \right]$$

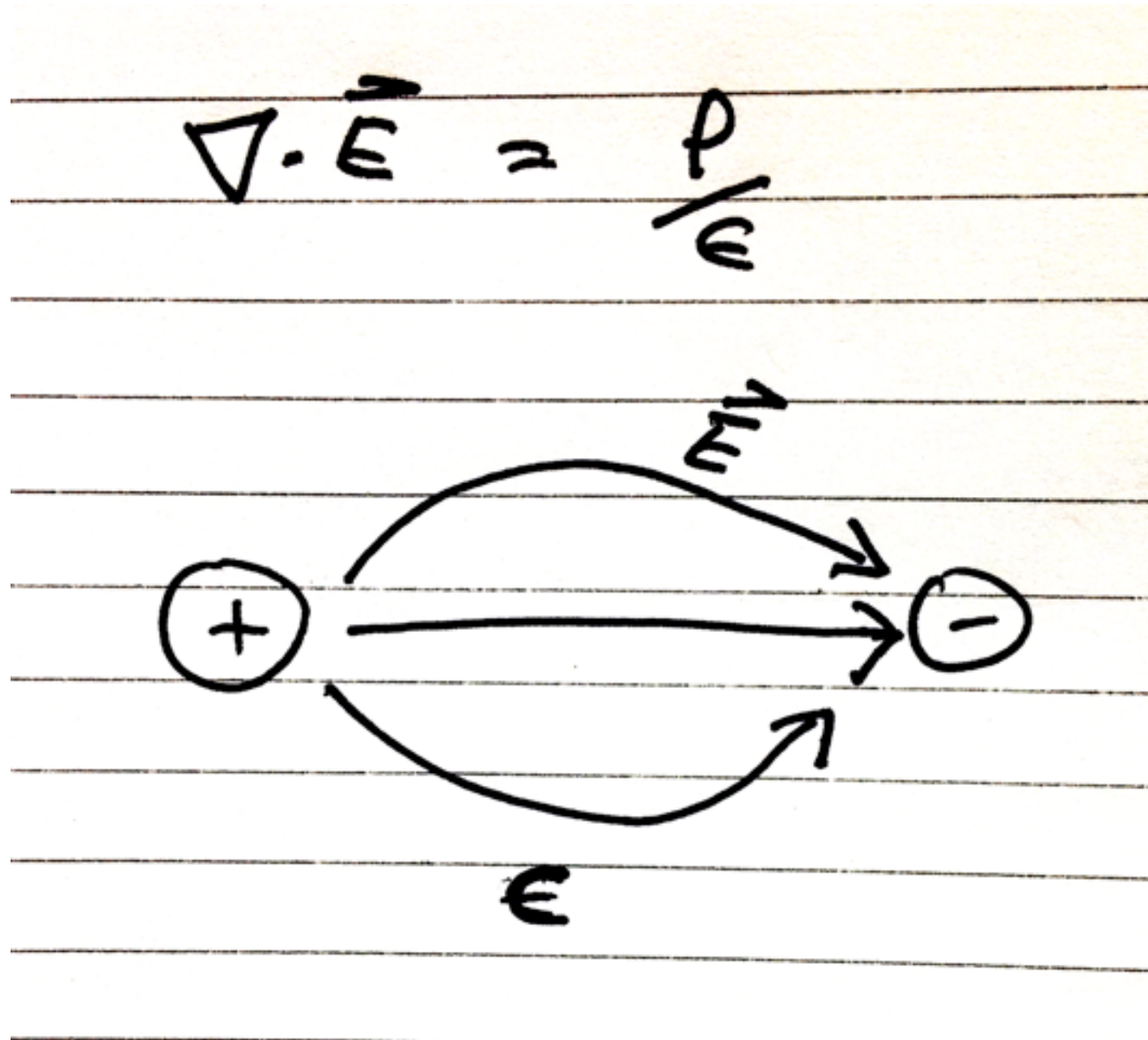
HENRY = UNIT OF INDUCTOR = L

A = AMP = CURRENT = I

$$V = L \frac{di}{dt}$$

Equation 3: $\nabla \cdot \mathbf{E} = \rho / \epsilon$

“Electric Fields Start and End on Opposite Charges”



Equation 4: $\nabla \cdot \vec{H} = 0$

“Magnetic Fields Start and End on Themselves”

“Magnetic Fields always form Closed Loops”

$$\nabla \cdot \vec{H} = 0$$



Dimensional Analysis:

$$I = V/R: \quad (\text{Resistor})$$

$$I = C \, dV/dt: \quad (\text{Capacitor})$$

$$V = L \, di/dt \quad (\text{Inductor})$$

Maxwell's Equations Imply that Circuit
Theory is a Subset of Electromagnetics

Maxwell in words:

- Electromagnetic Fields exist in Inductors
- Electromagnetic Fields exist in capacitors
- Electric Fields start and end on opposite charges
- Magnetic Fields start and end on themselves
- Electromagnetic Fields require alternating current to propagate without wires

The “Constants”

σ = conductivity = metals [1/ohms/meter]

ϵ = permittivity = dielectrics [farads/meter]

μ = permeability = ferrites [henrys/meter]

As far as radio waves are concerned, the entire universe is made up of these 3 things

About Polarization:

- Polarization is defined as the direction of the Electric Field in a radio wave, and:
- Maxwell's Equations state that Electric Fields start and end on opposite charges, and:
- Coax cables have conductors with opposite charges (ground & signal), so:
- We can force the desired polarization by correctly locating the coax feed point.

Antenna Definition:

An antenna is a physical structure that sends
and receives Radio Waves

The essential question is
“What is a Radio Wave?”

Stories

- The Valley of the Blind men
- The Beach

Radio Wave Properties:

Invisible to the human eye

Travels 7 times around the Earth in one second

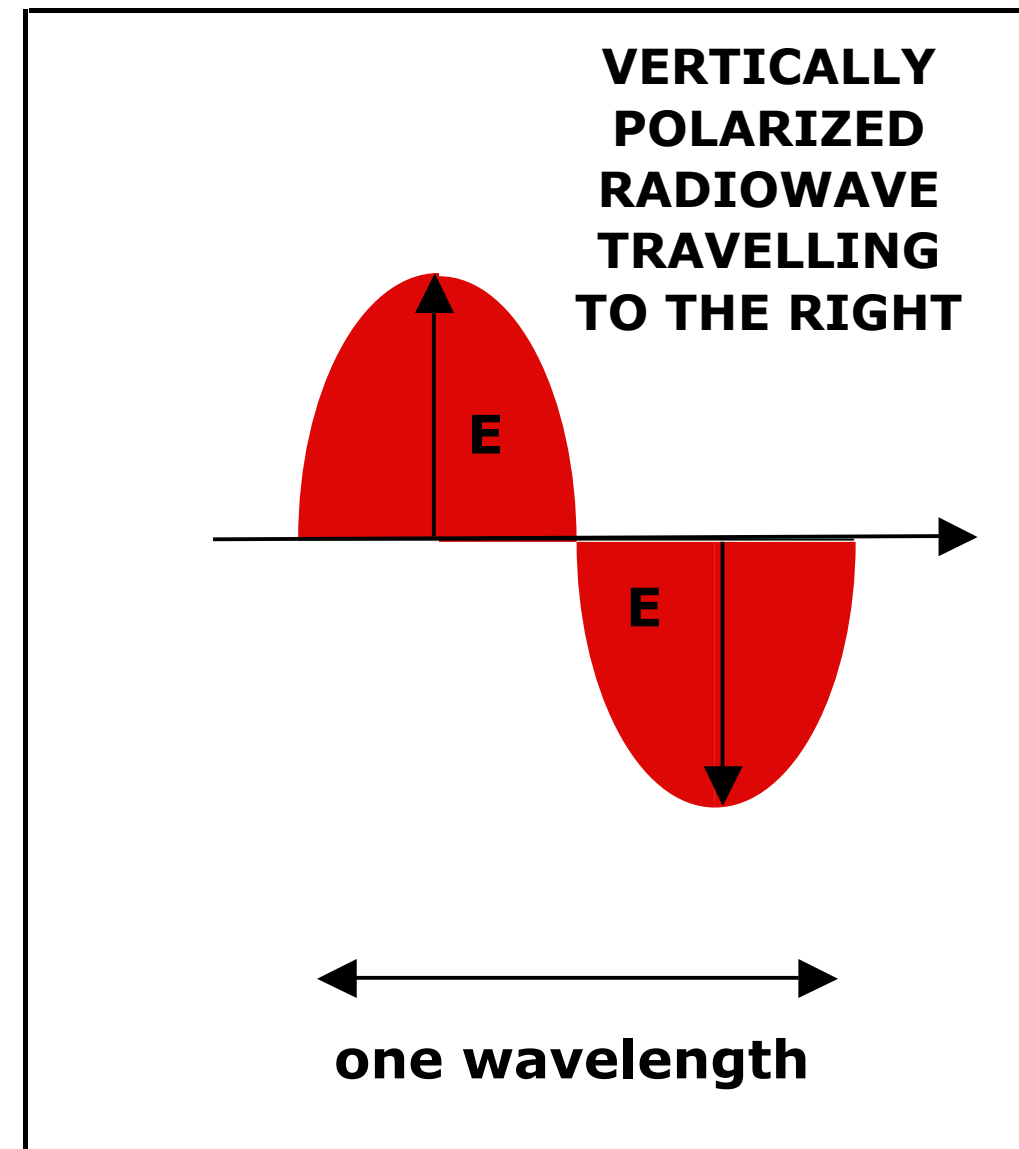
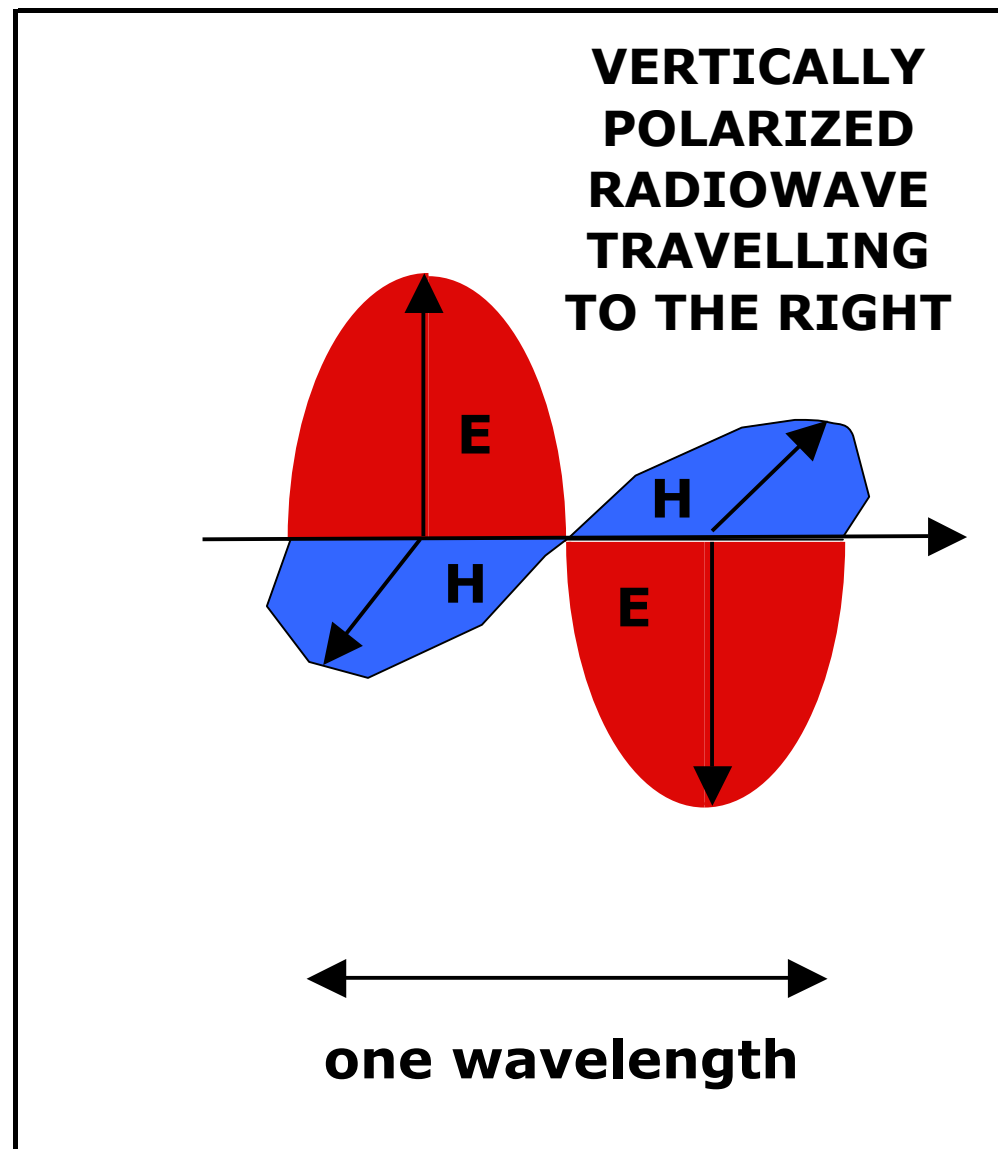
Has definite size and shape

Has a definite orientation

propagates without any wires

Radio Wave Picture:

Simplified:



“Capturing the Elusive”

- Must build a “mousetrap”
 - Need to guess what Radiowave looks like, then
 - design a structure to capture it
- My college professor once told me, “Antenna Design is easy; just fit Maxwell’s Equations to the boundary conditions”

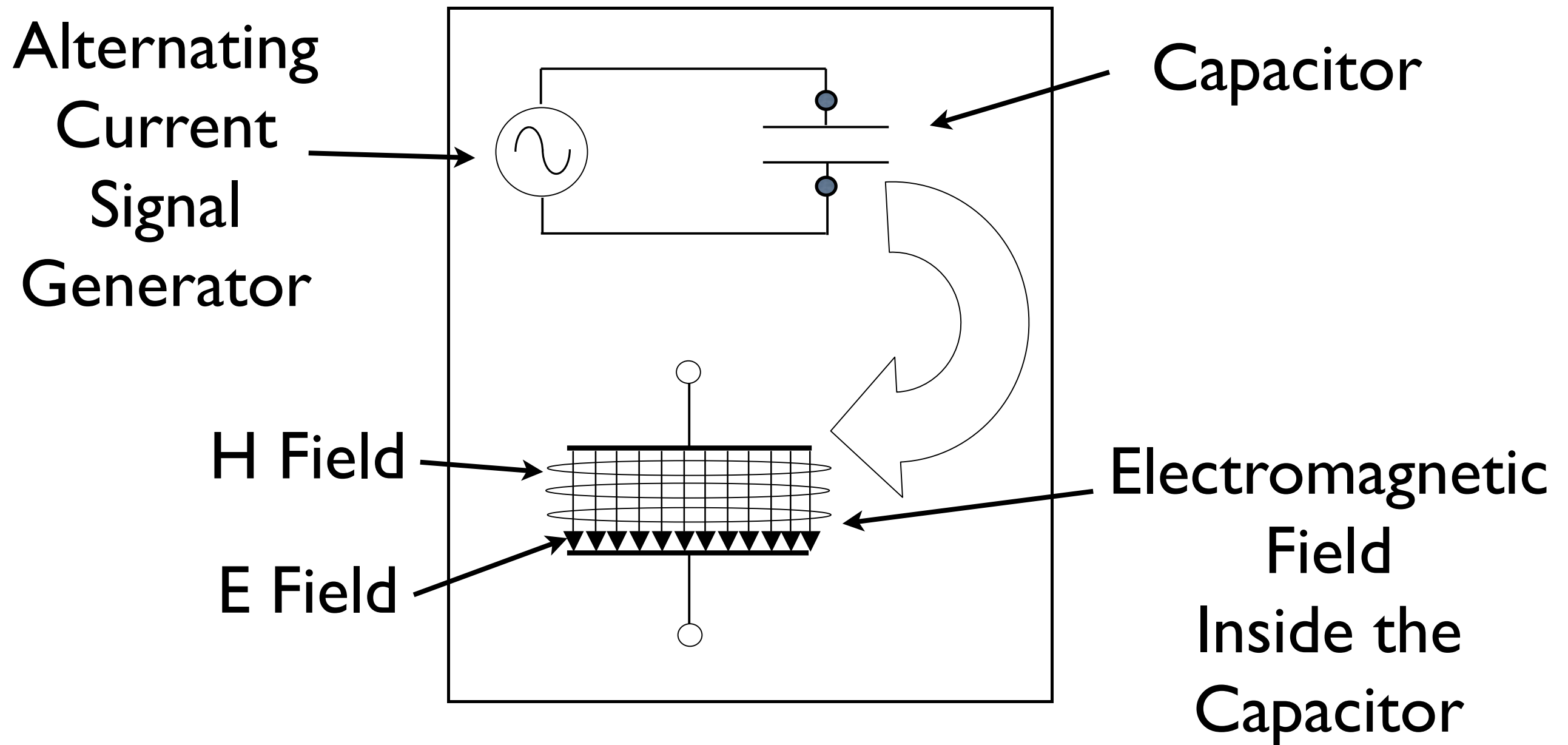
About Boundary Conditions:

- Electric Fields are perpendicular to conductors
- Maximum Current occurs at a short circuit
- Minimum Current occurs at an open circuit
- Radio Wave must “Fit the Structure”

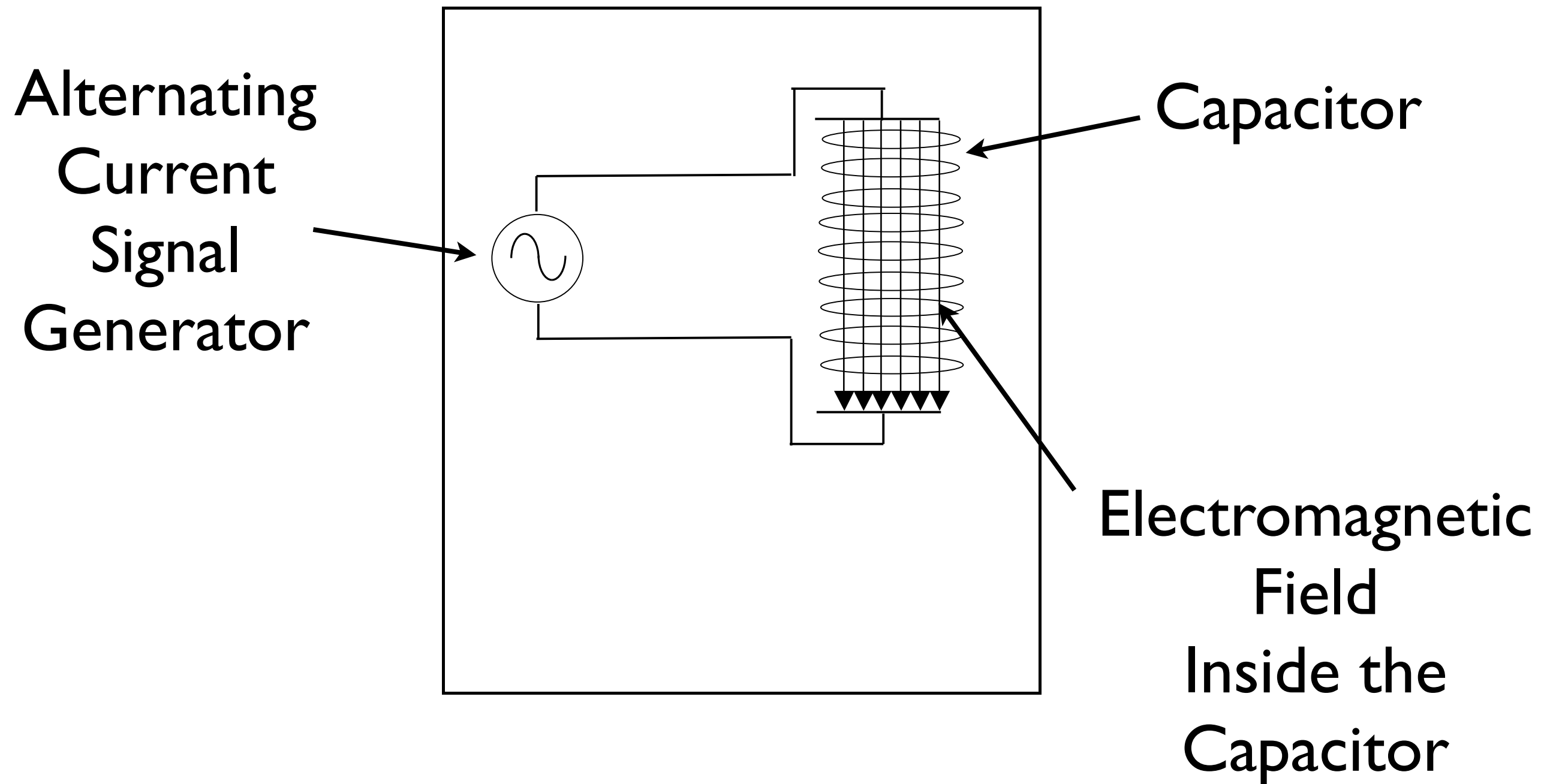
Antenna Fundamentals

- Let's make an Antenna from Maxwell's Equations:
 - Need alternating current
 - Need a structure based on a capacitor
 - Need “separation of opposite charges”
 - Need to “fit the wave” to the structure

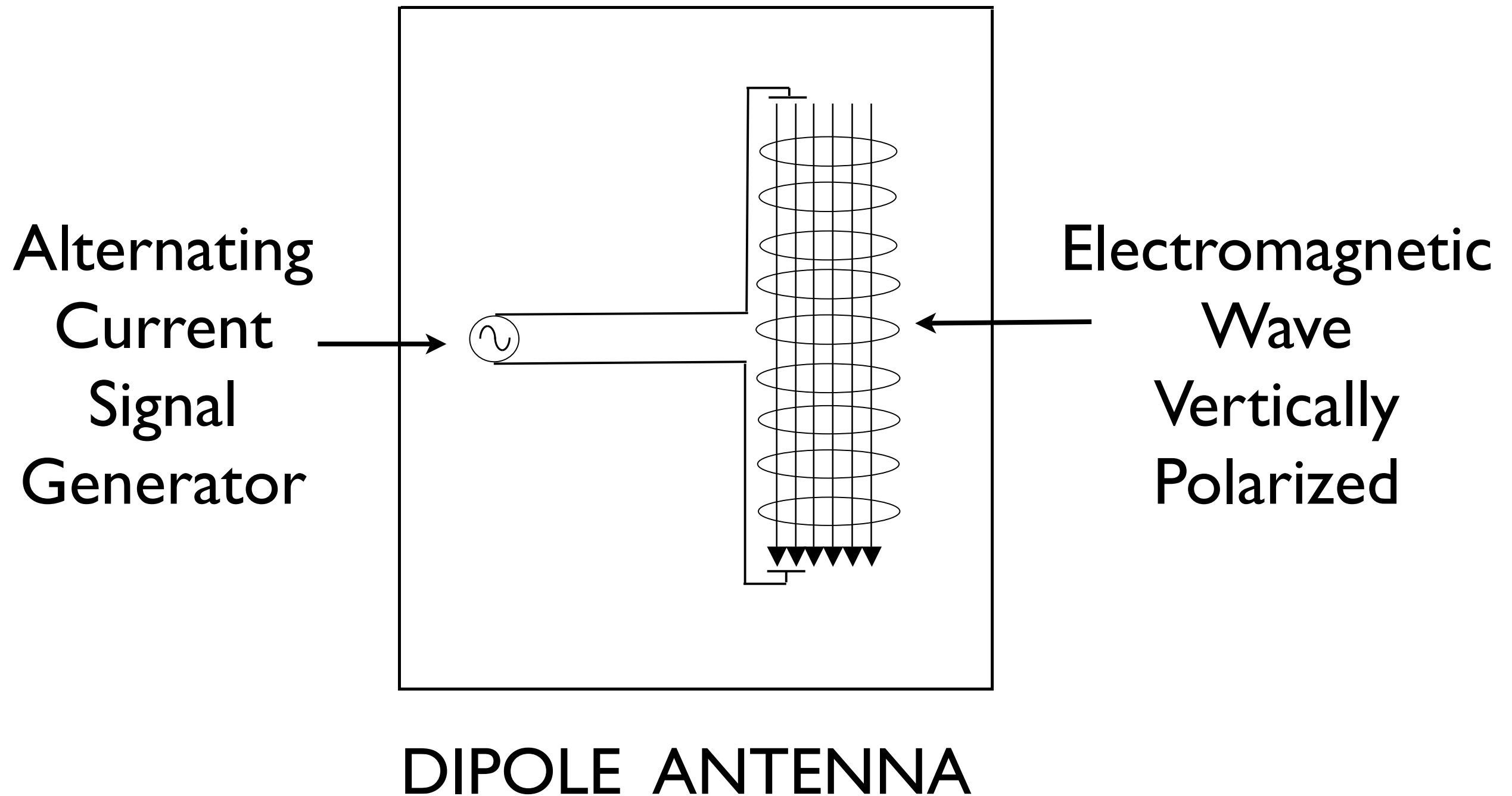
Basic Capacitor Circuit



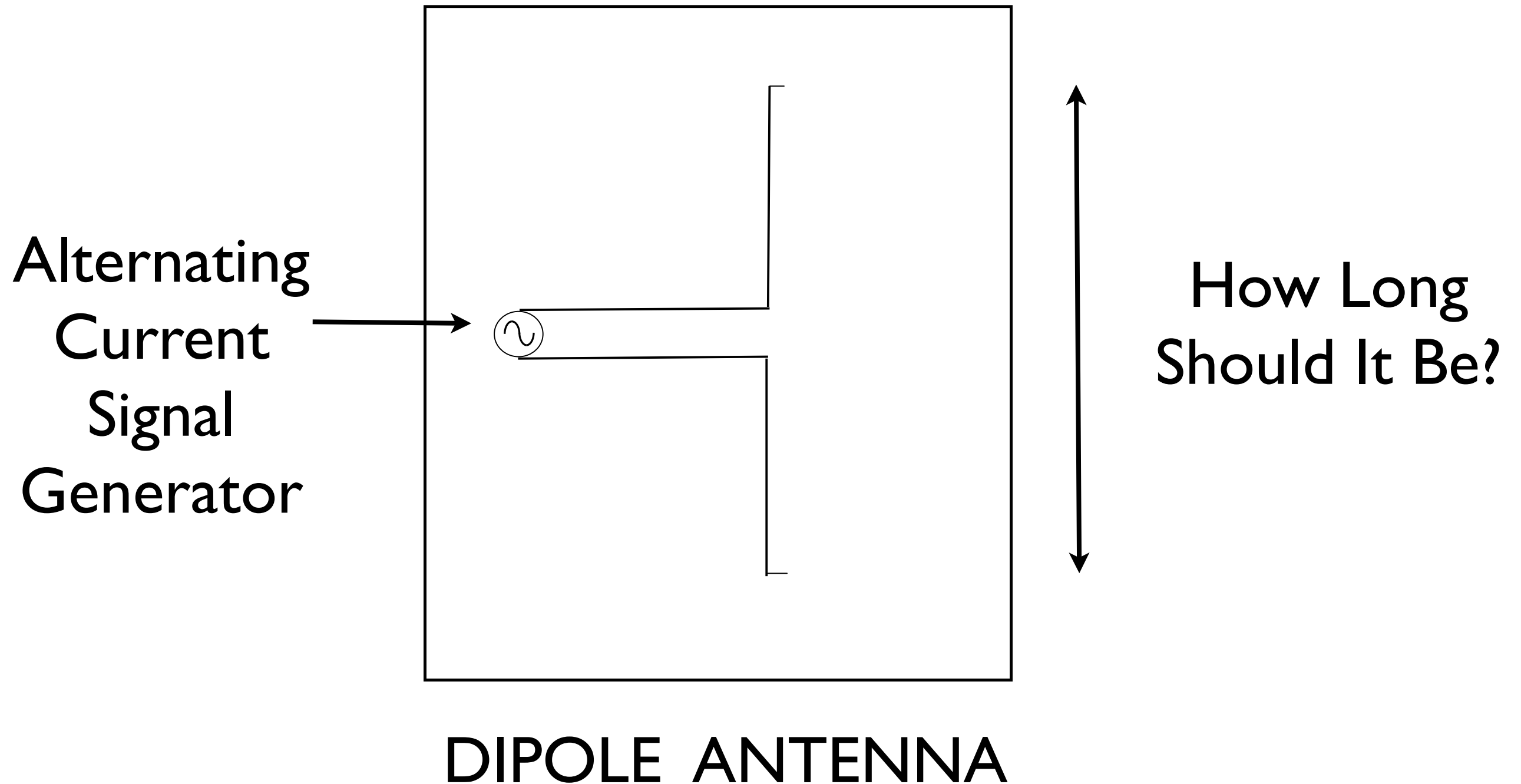
Capacitor “Spread Apart”



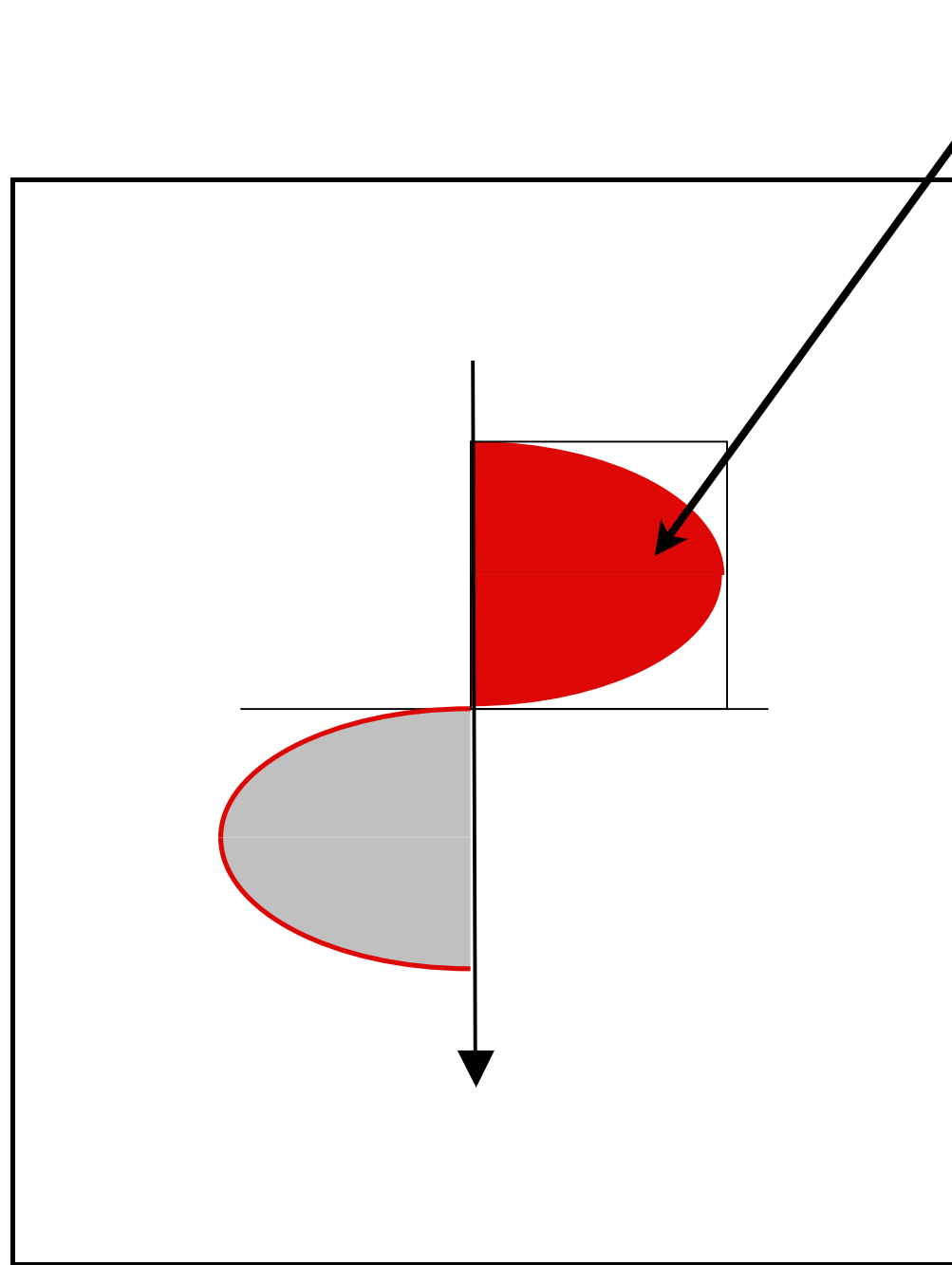
Capacitor “Spread Way Apart”



How Far to Spread it?



Structure Captures This Part of the Wave



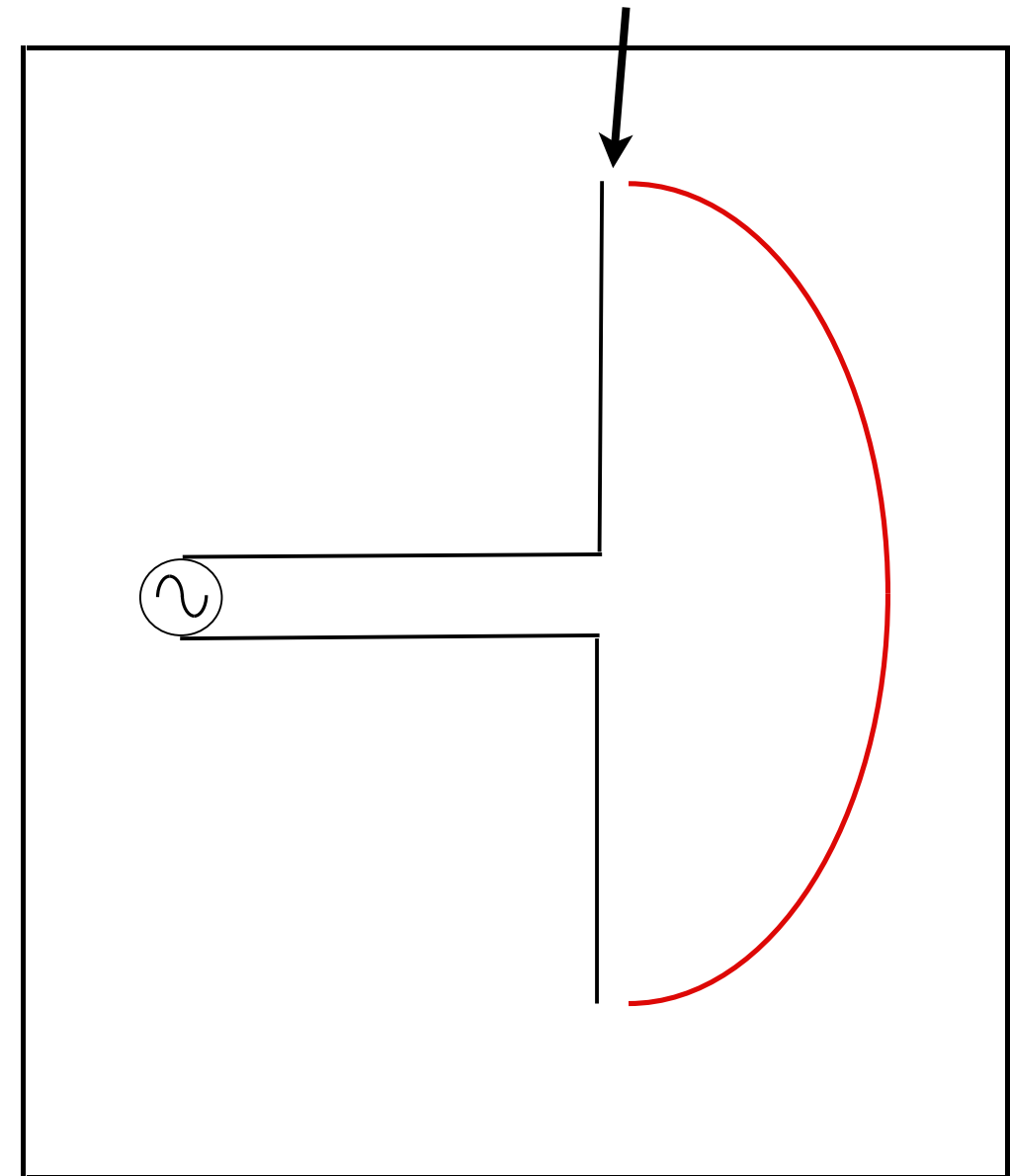
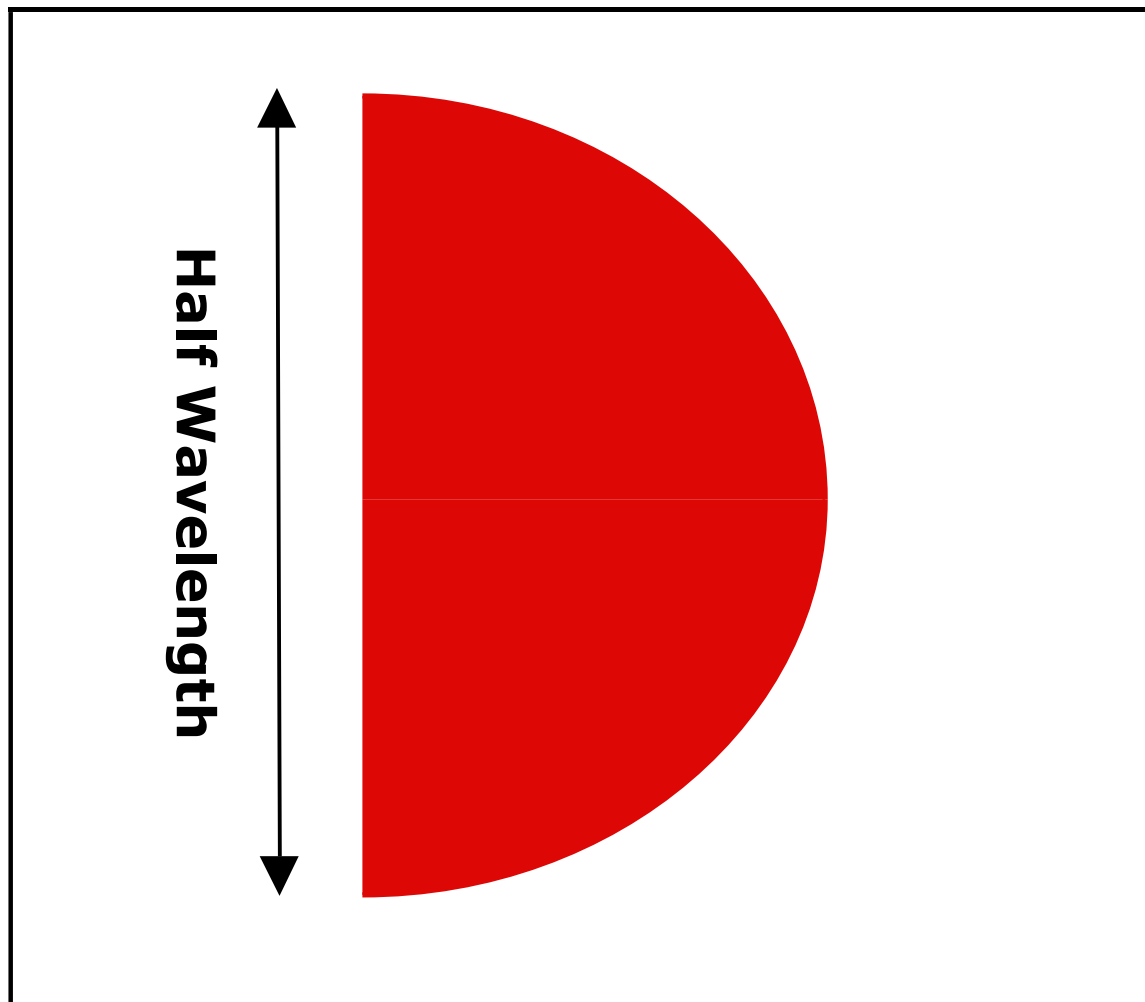
Must Be Halfwave Long

Starts at Current Minimum

Ends at Current Minimum

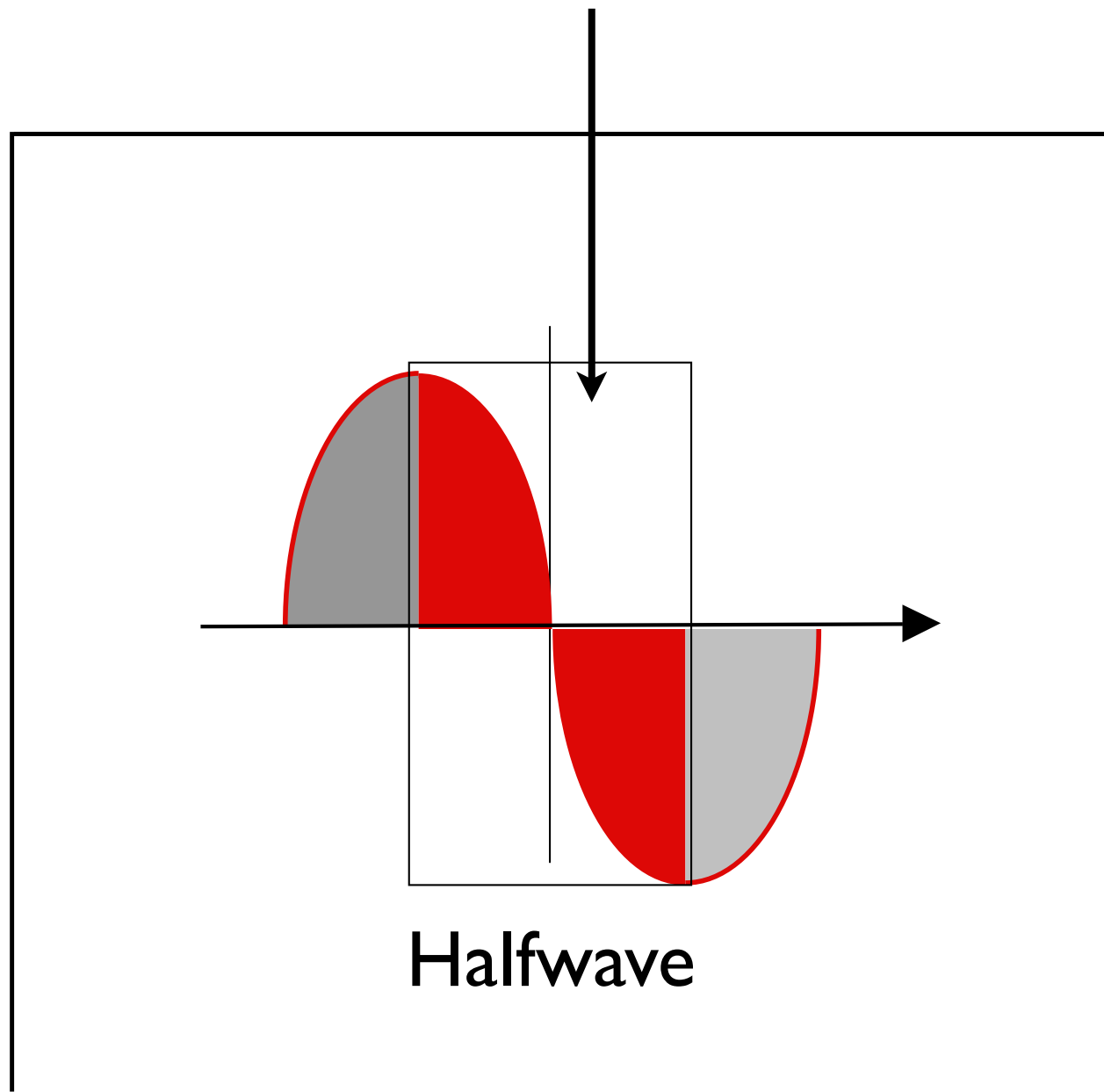
Structure “Fits The Wave”

Current Minimum
at Ends of Wire



DIPOLE ANTENNA

Let's Build a Structure That Captures This Part of the Wave:

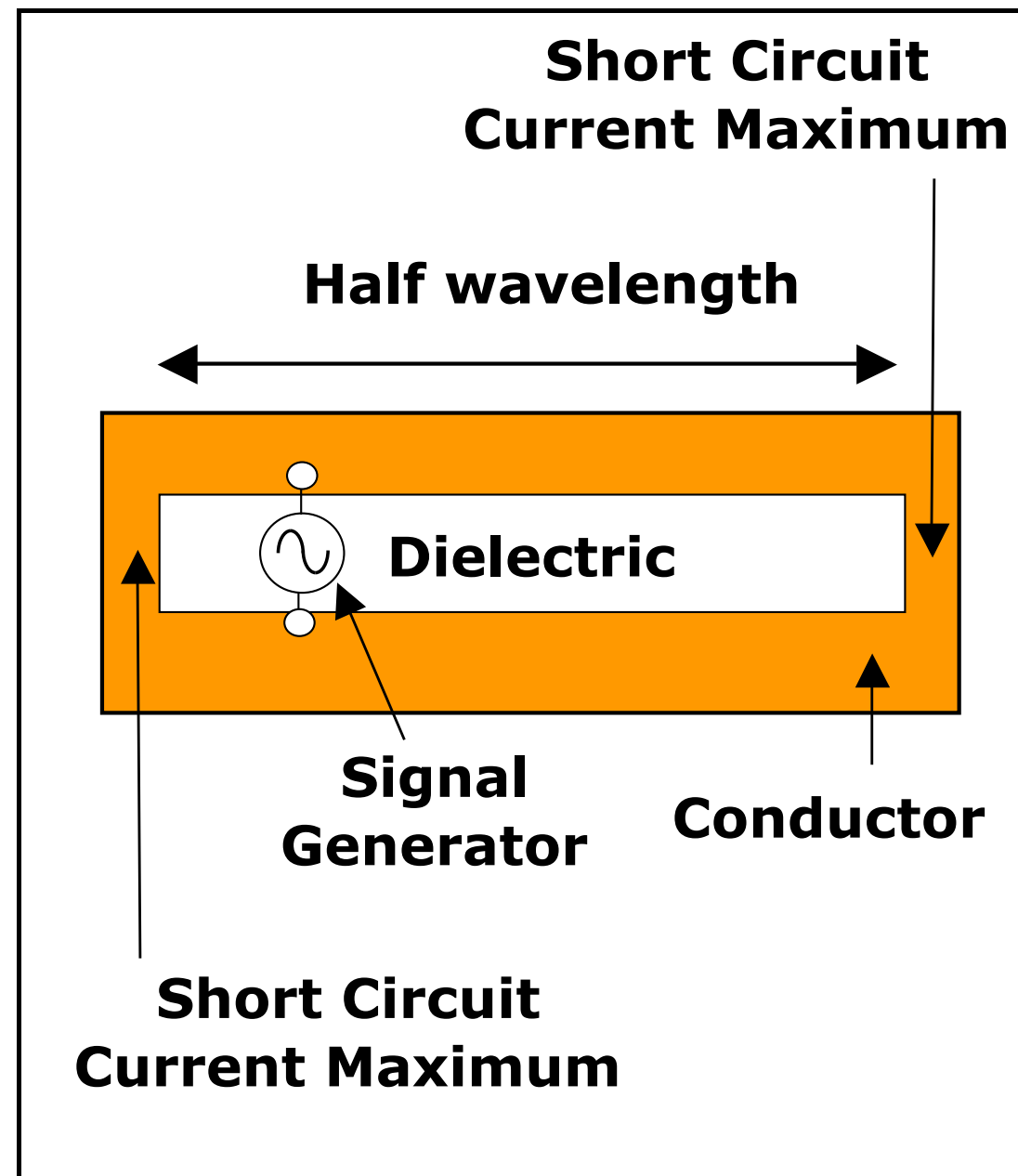


Must Be Halfwave Long

Starts at Current Maximum

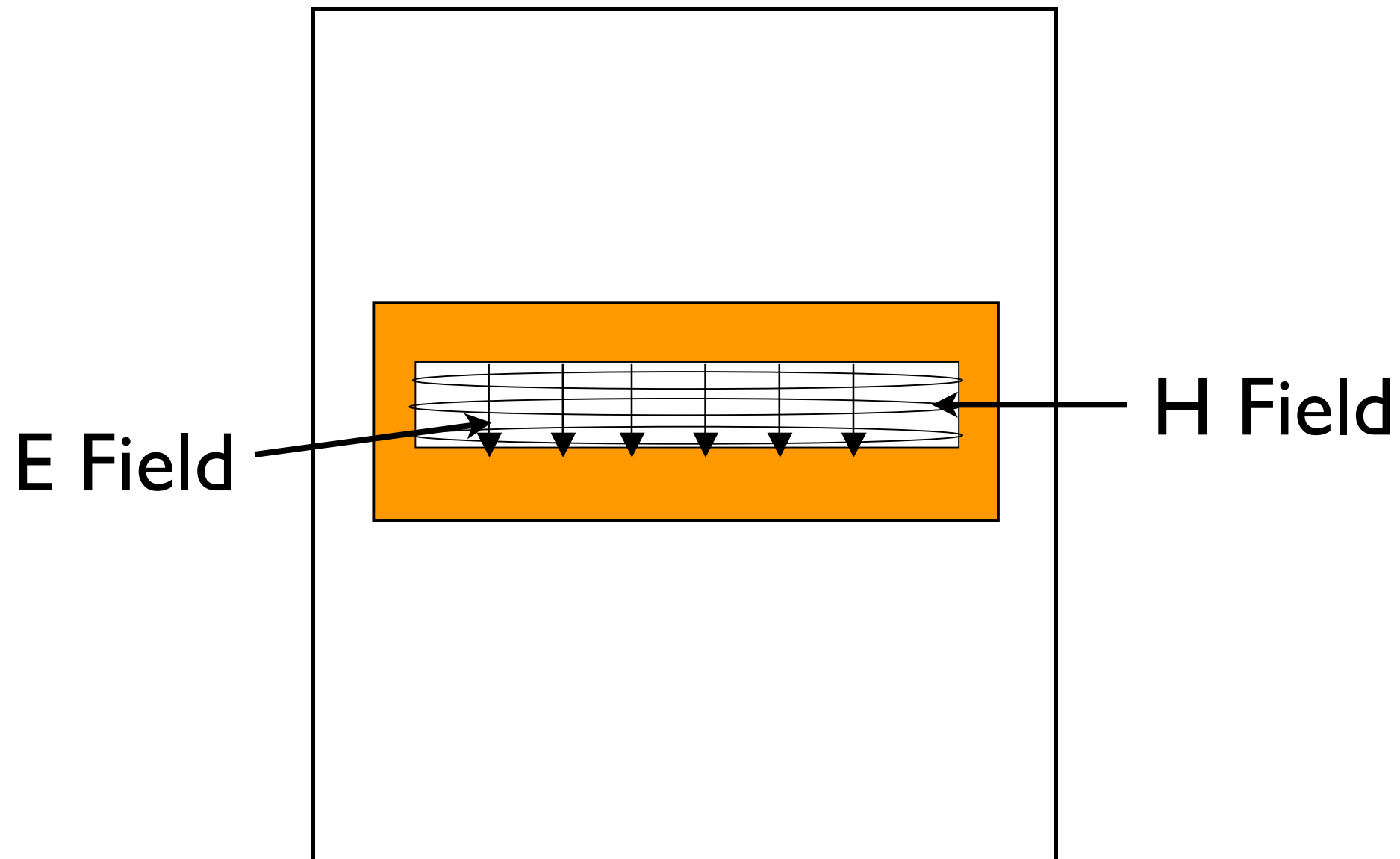
Ends at Current Maximum

Let's Build a Structure That Captures This Part of the Wave:



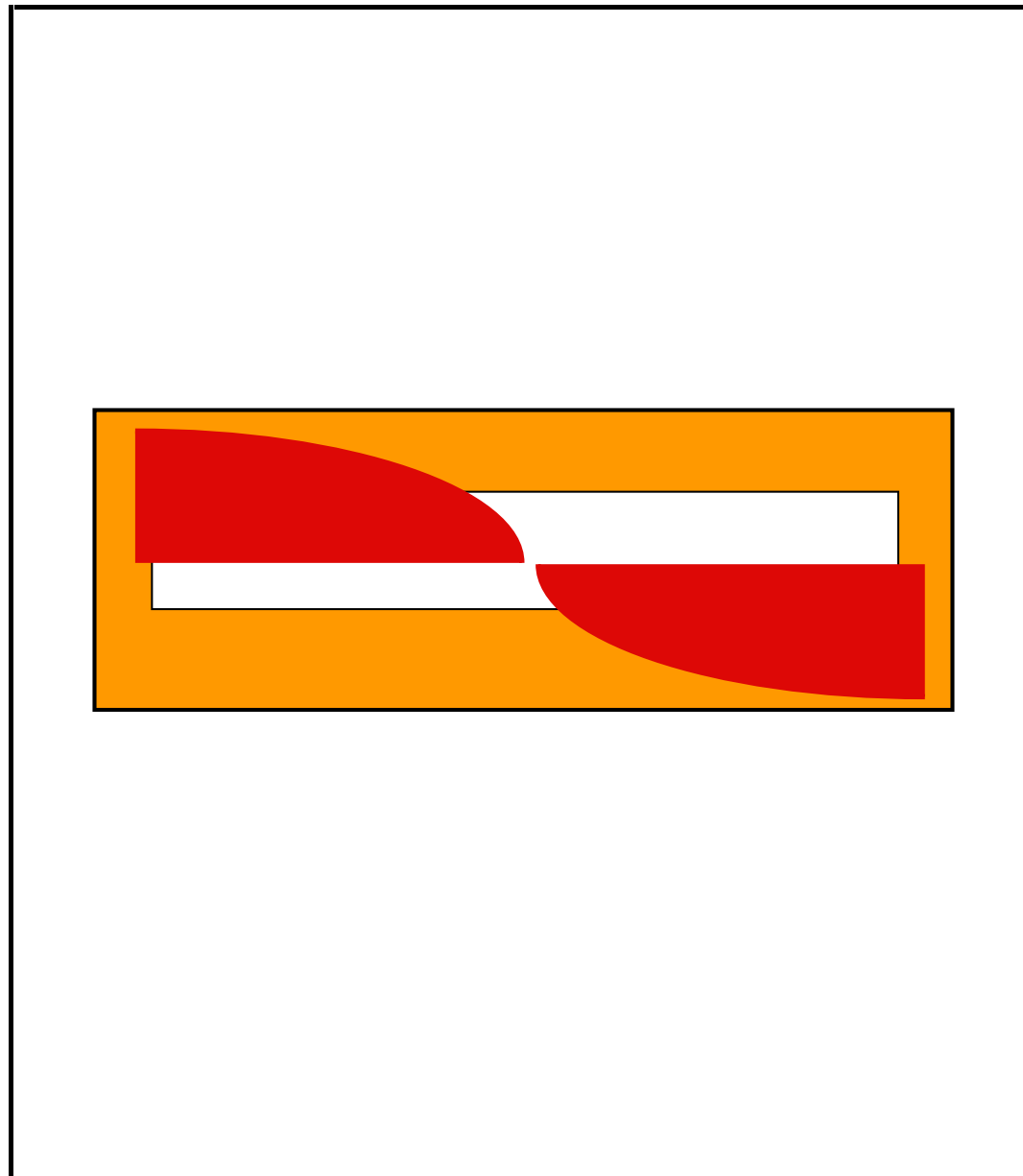
Halfwave Slot Antenna

Electromagnetic Field inside the Slot



Halfwave Slot Antenna

Captures the Middle Part of the Wave:



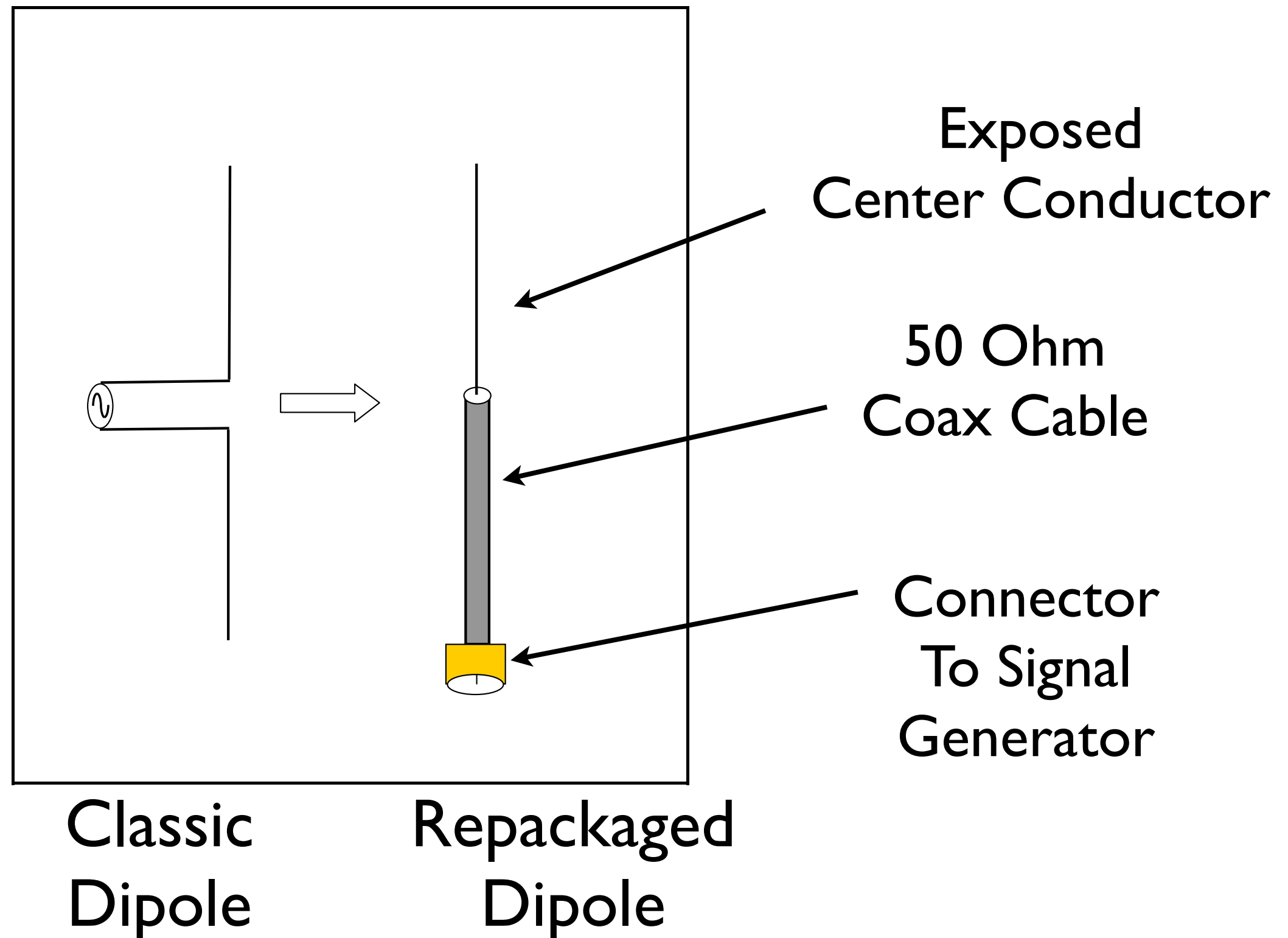
Wave Captured
on Structure

Halfwave Slot Antenna

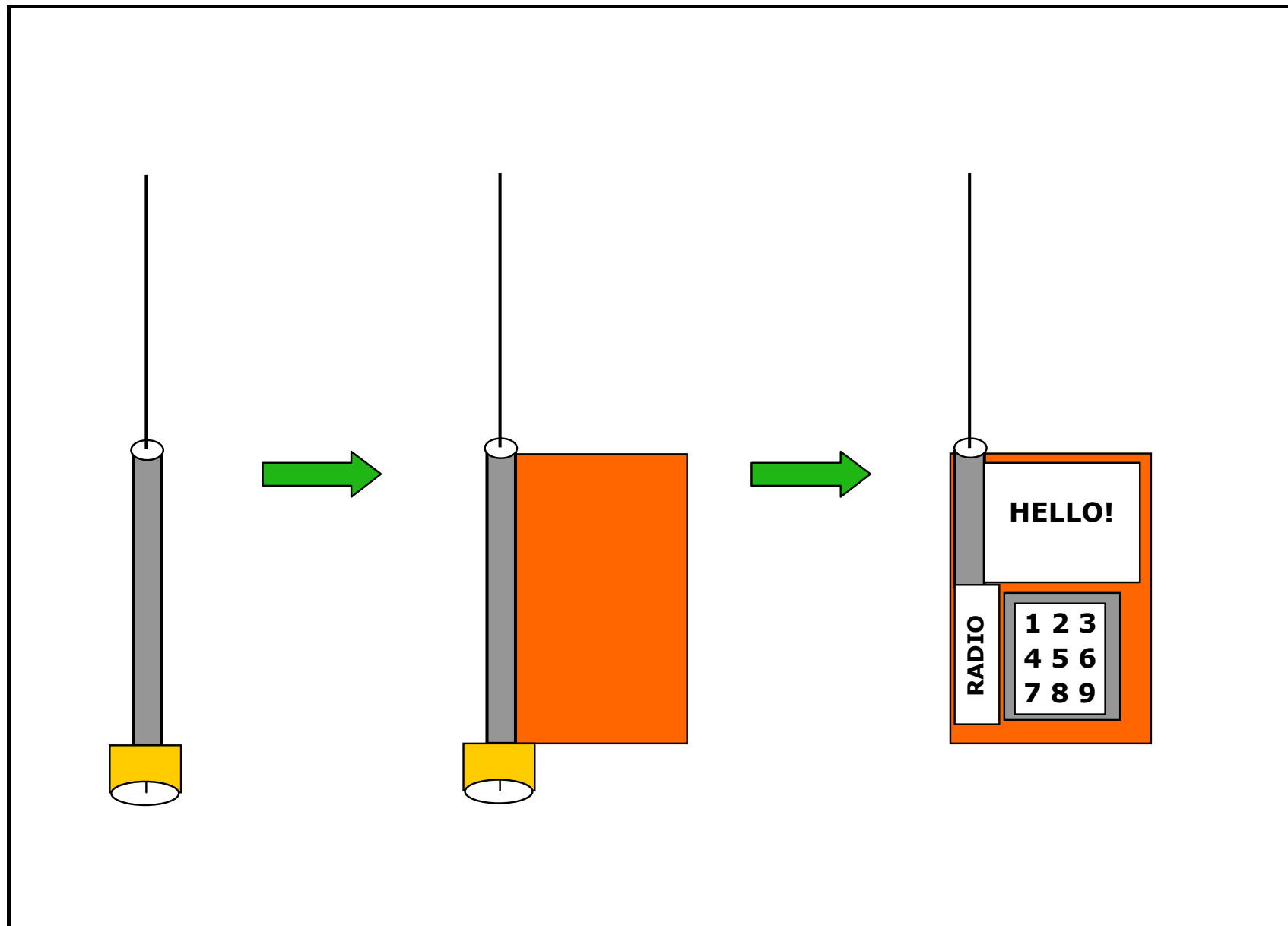
Fundamental Antennas

- Dipole Antenna
- Slot Antenna:
 - Need alternating current
 - Need a structure based on a capacitor
 - Need “separation of opposite charges”
 - Need to “fit the wave” to the structure
 - Need structure to be Half wavelength

Let's turn fundamental antennas into phone antennas; Start by Repackaging the Classic Dipole:

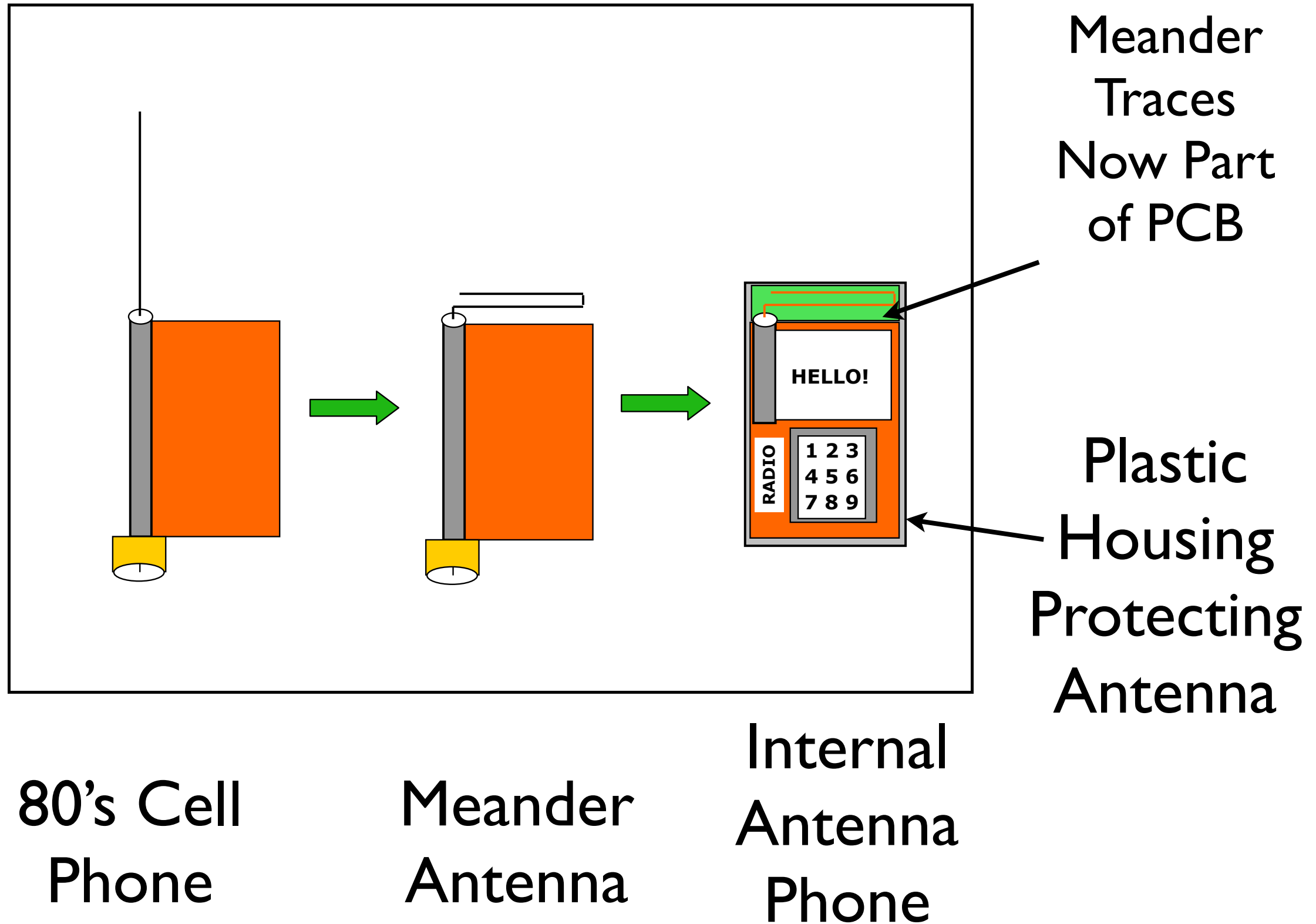


Repackaged Dipole to 80's Cell Phone:



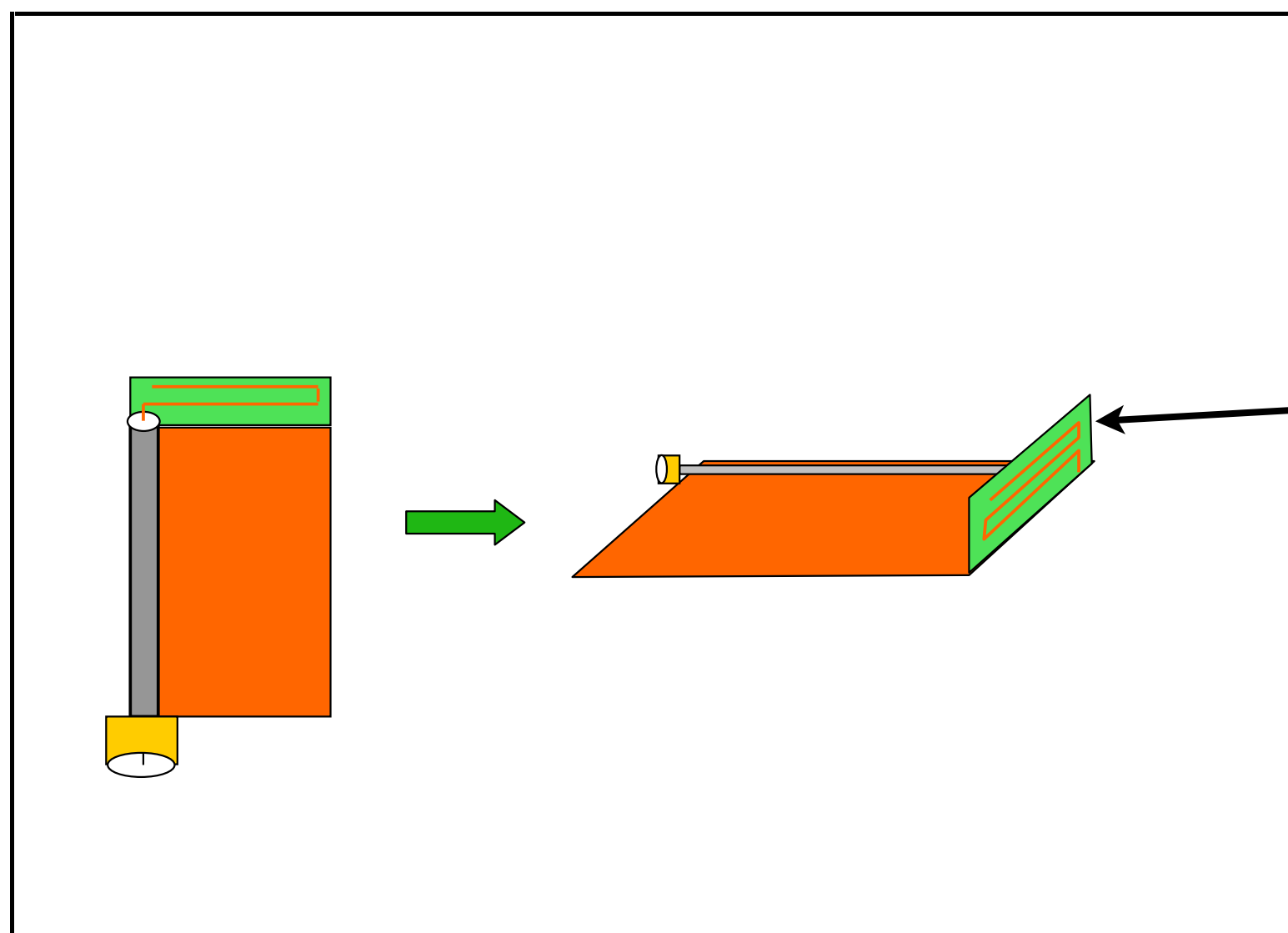
Repackaged Dipole + Wide Ground Plane = 80's Cell Phone

80's Cellphone to Meander Antenna



In-Line Meander to Perpendicular Meander Antenna

Phone
is Too
Long!

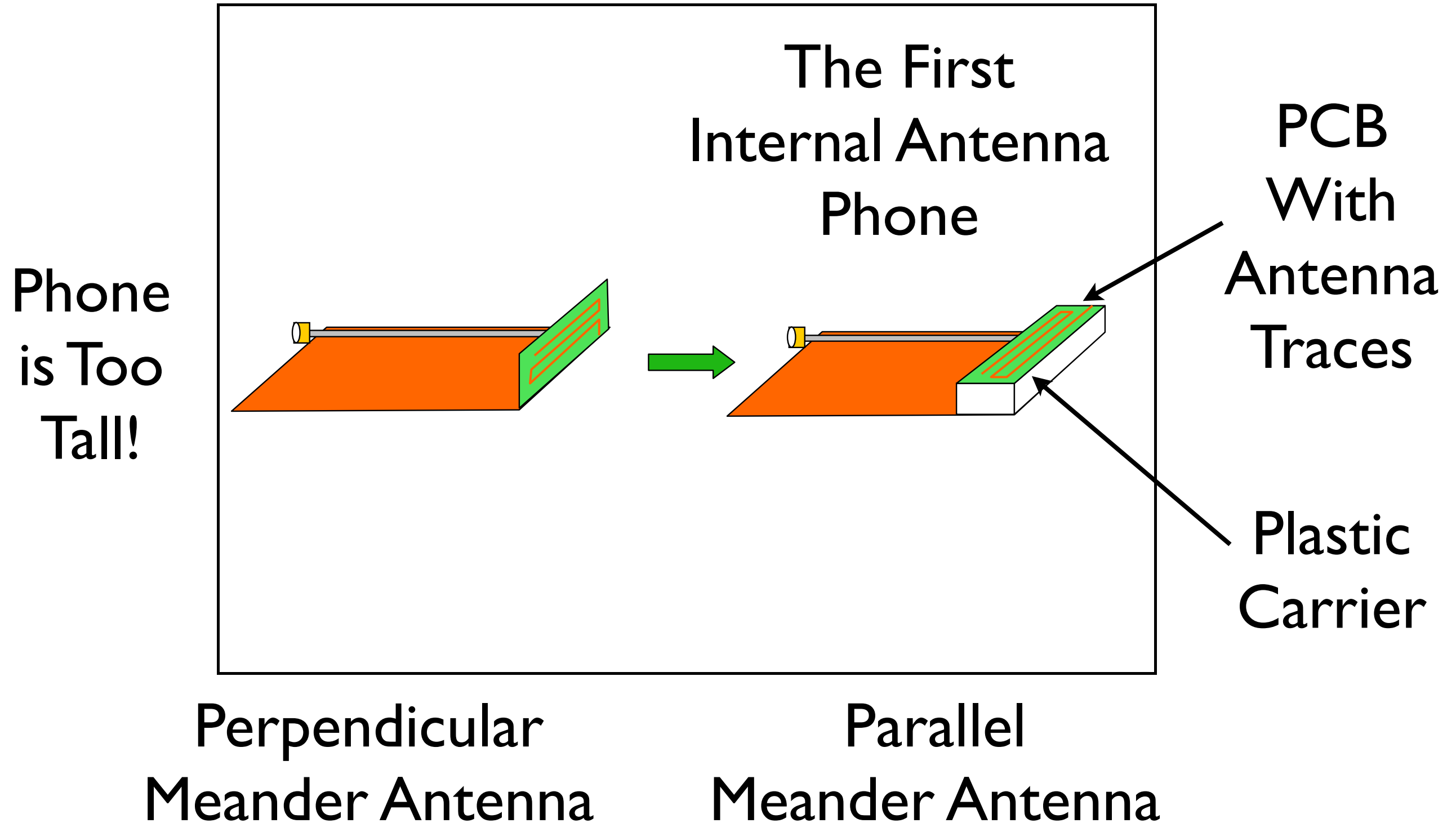


PCB
With
Antenna
Traces

Meander
Antenna

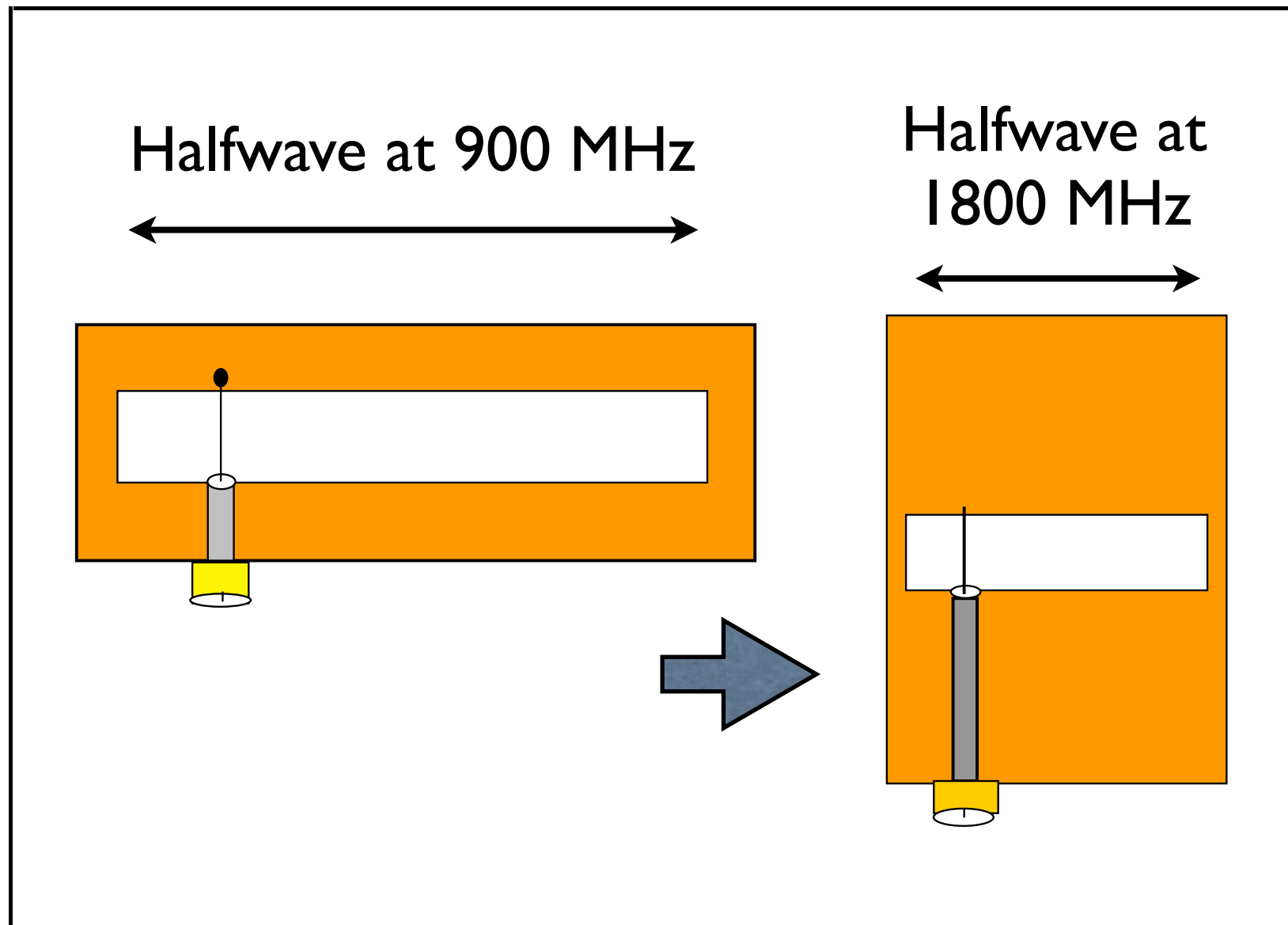
Perpendicular
Meander Antenna

Perpendicular Meander Antenna to Parallel Meander Antenna



- Everything's Going Well:
 - Phones have Internal Antenna, but...
- Now, they want MultiBand Internal Antenna!
- How to implement that?
 - Use Parallel Meander Antenna for Lowband
 - Use Slot Antenna for Highband
 - Combine the two Feedpoints into one Feedpoint to Create MultiBand Antenna

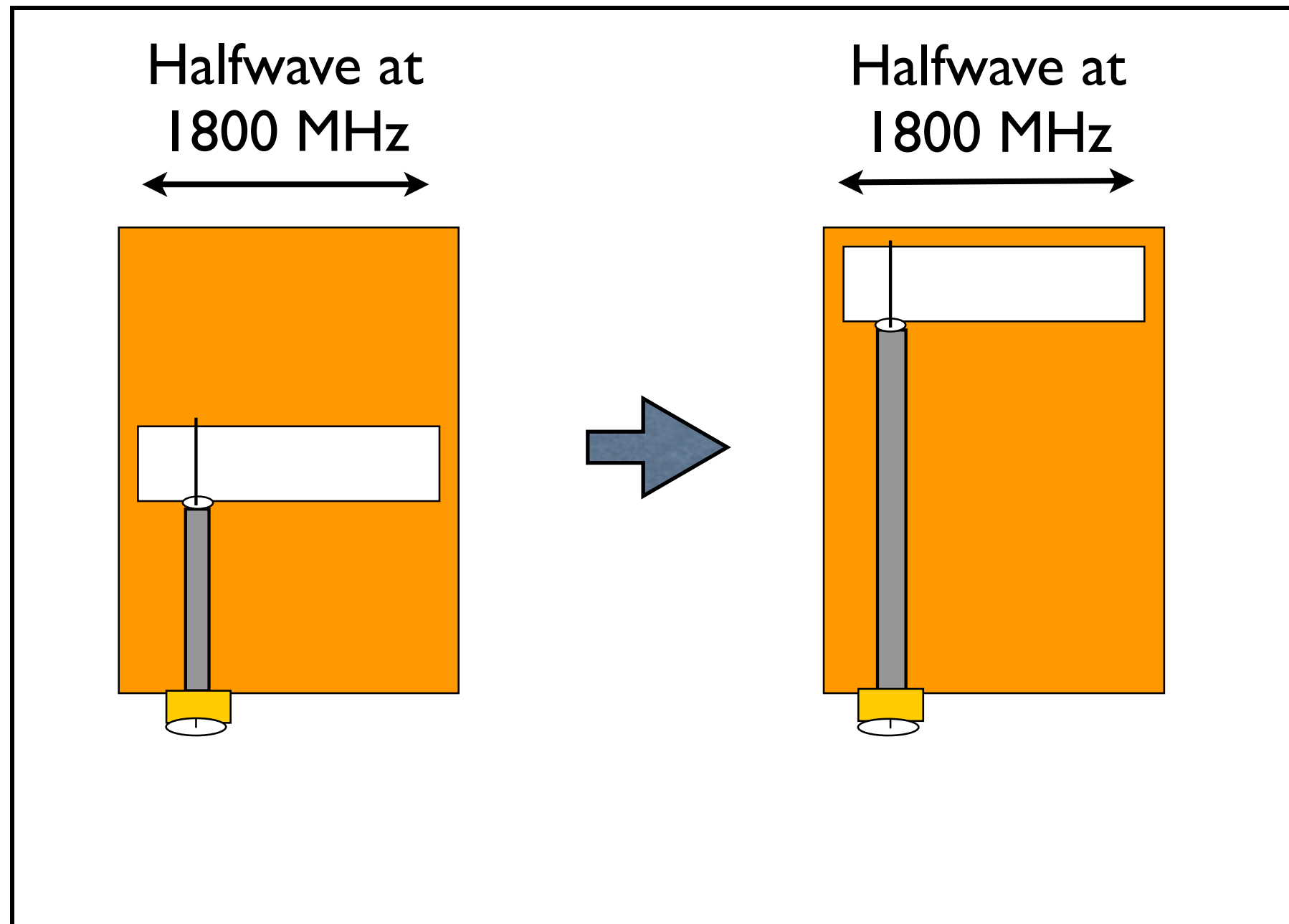
Highband Antenna: Start with a Classic Slot Antenna



Classic
LowBand
Slot Antenna

HighBand Slot
on Phone
GroundPlane

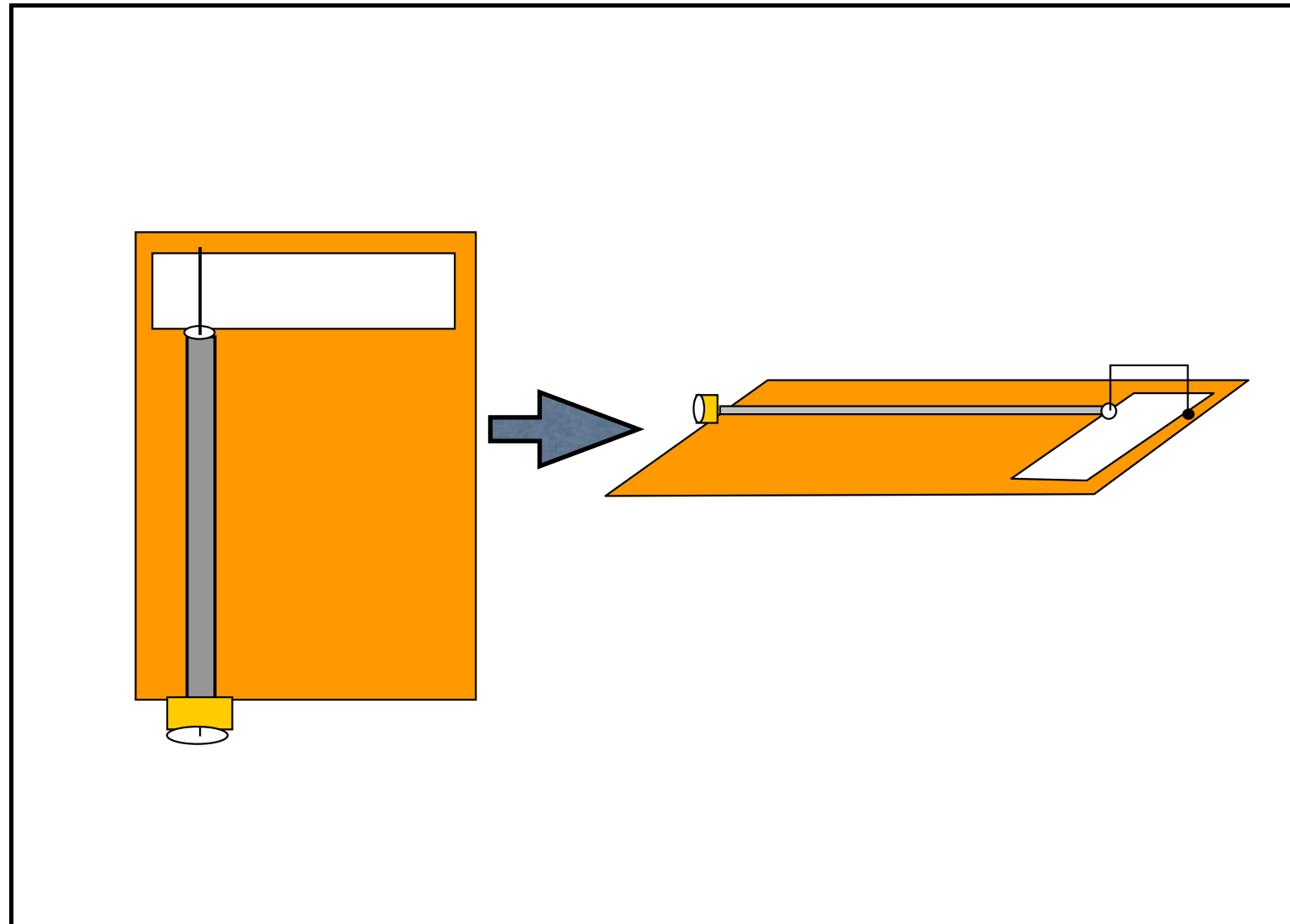
HighBand Antenna: Classic Slot Antenna to Edge Slot



HighBand Slot on
Phone GroundPlane

HighBand Slot Moved
to GroundPlane Edge

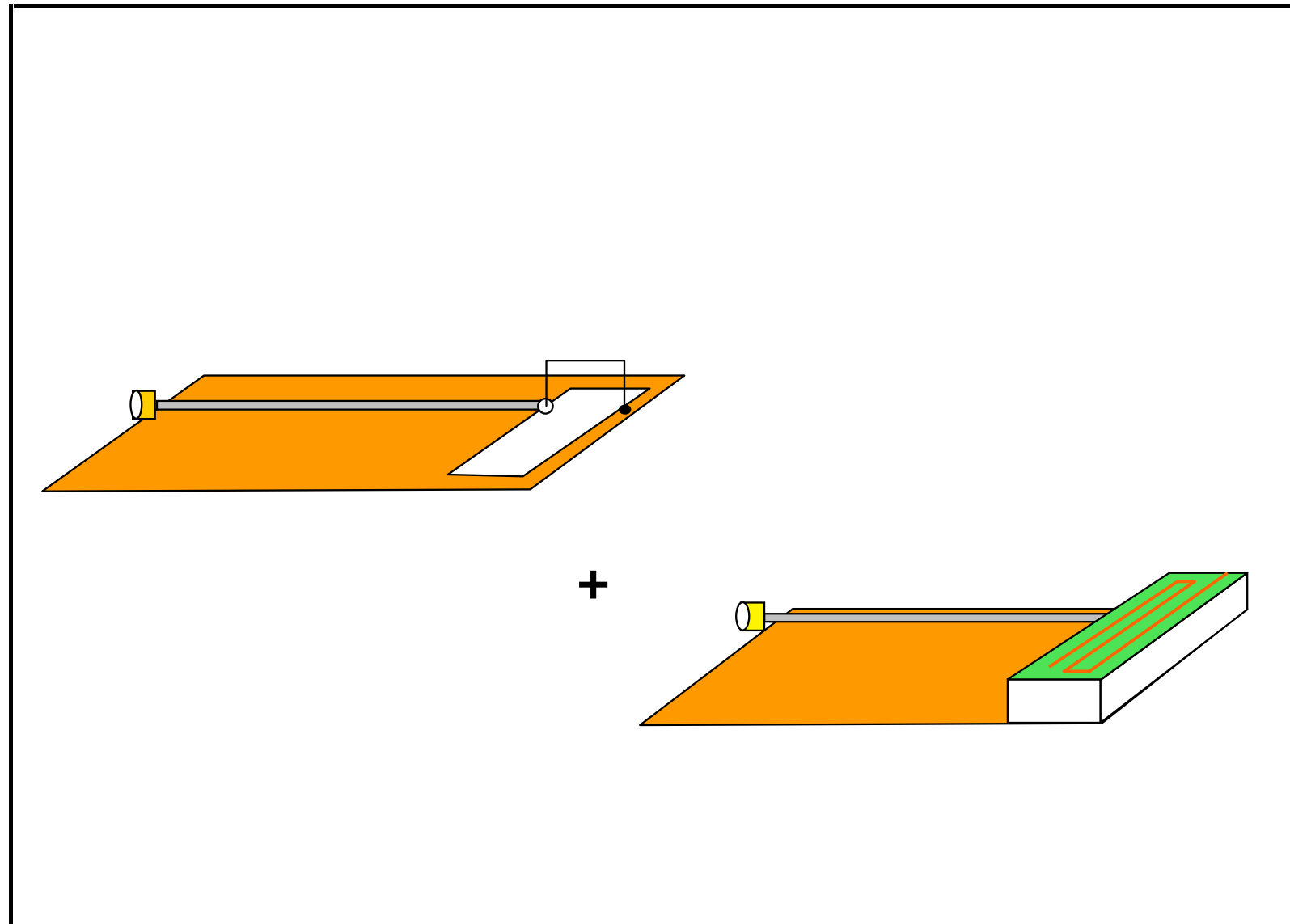
HighBand Antenna: Edge Slot to Raised Feed Edge Slot



HighBand
Edge Slot

HighBand
Edge Slot with
Raised FeedPoint

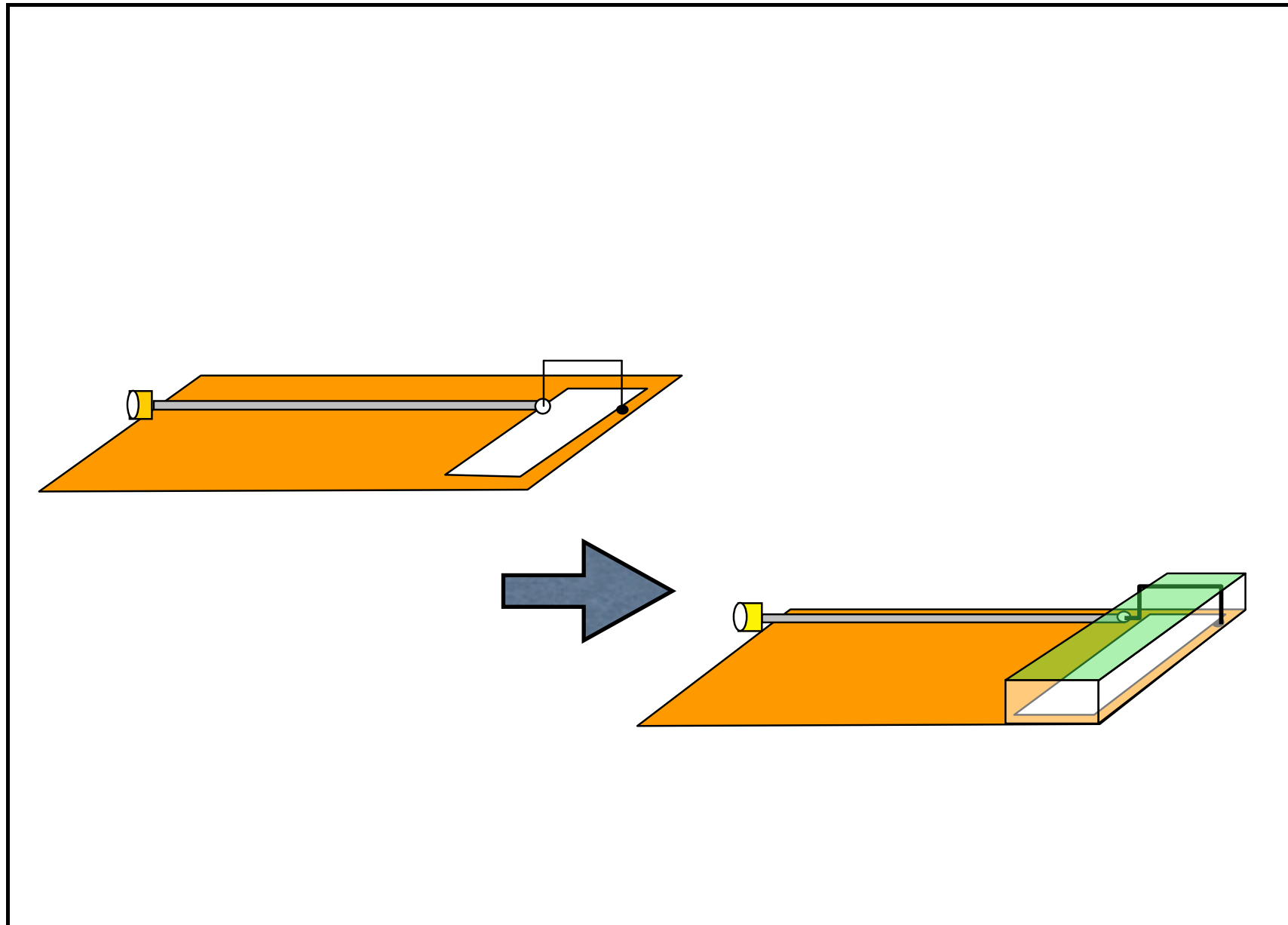
MultiBand Antenna: Need to Combine Antennas Together



HighBand
Edge Slot
with Raised
Feedpoint

LowBand
Parallel
Meander

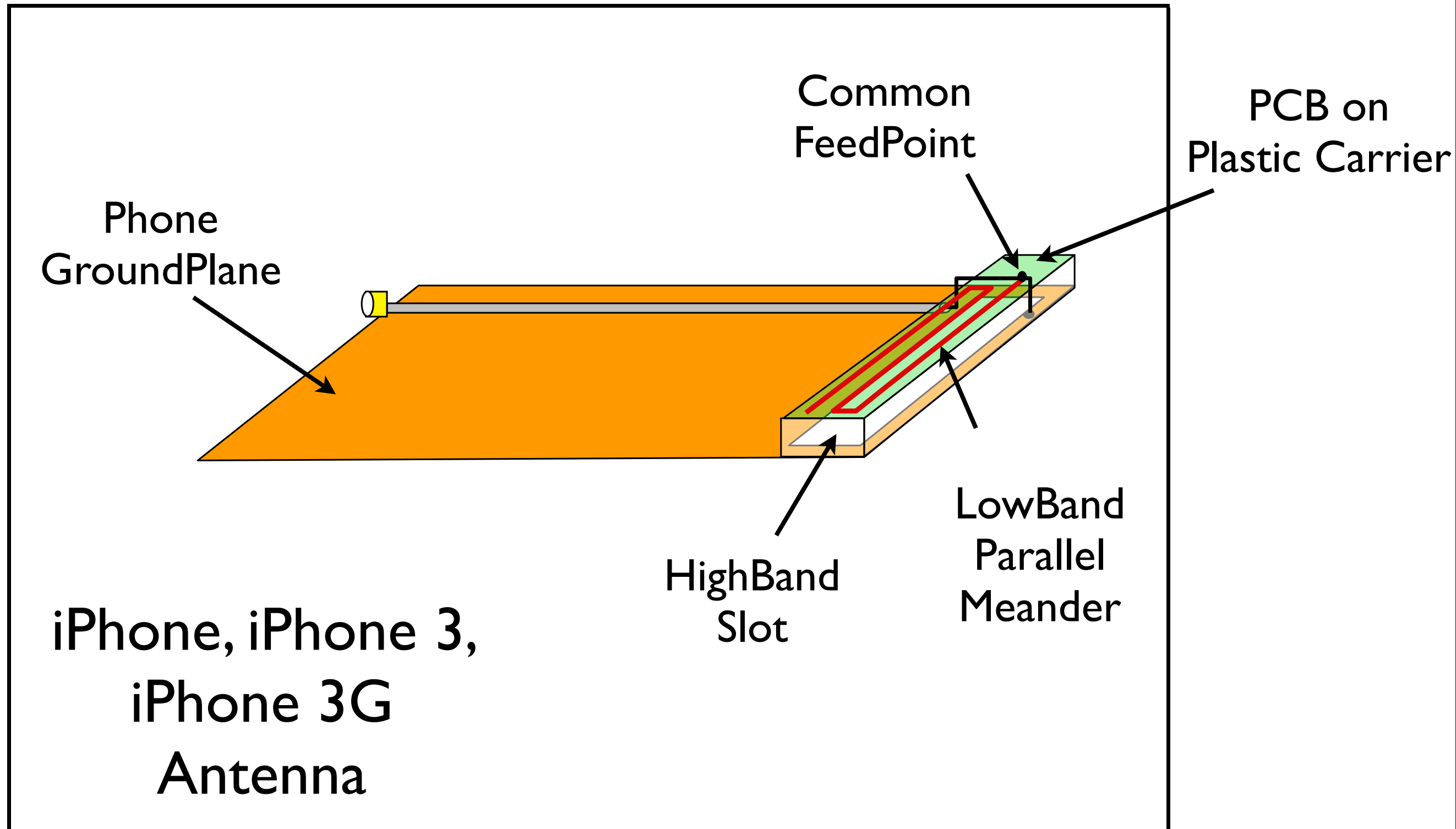
MultiBand Antenna: Need to Combine FeedPoints and Antennas



HighBand Edge
Slot with Raised
Feedpoint

Highband Edge Slot
with Plastic Carrier
and PCB

MultiBand Antenna: Connect FeedPoints Together



Q & A

Rob Hill
AntennaMagic LLC
2125 Louis Holstrom Dr
Morgan Hill CA 95037
antennamagic@gmail.com
408-386-9554